Giant planets around M, L, T dwarfs in the Infrared (*GIMLI*)

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Exoplanet Science Fair

JPL

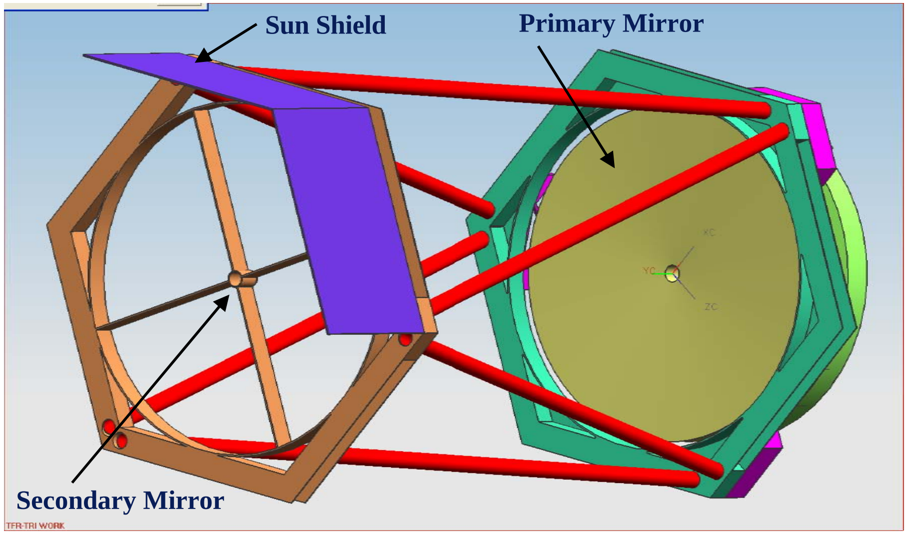
GIMLI: Steve Pravdo, JPL

- Science objective is to distinguish between competing models of planetary formation by:
  - Surveying ~2000 low-mass stars for companions, which include Extrasolar Giant Planets (EGPs) down to Uranus mass, as well as Brown Dwarfs (BDs)
  - Measuring the masses, distances, and luminosities of the low-mass targets and their companions
  - Testing theoretical mass-luminosity models and developing accurate mass-luminosity relationships

GIMLI is an astrometry / coronagraphy mission with a 1.4 m aperture telescope, and a 5 year mission lifetime.

- Orbit: Distant Retrograde Orbit
- Estimated observatory mass: 275 kg (Including 30% contingency)
- Estimated spacecraft mass (including telescope): 883 kg
- Spacecraft configuration based on Ball BCP 2000 RSDO bus architecture
- Estimated observatory power consumption: 135 W
- Mission duration: 5 years
- Detectors: Hawaii 2RG HgCdTe, 1 – 2.5 μm
- Temperature: 140 K (instrument), Passive thermal cooling
- Pointing requirements: 1 arcsec/sec stability, use FSM to achieve 0.01 as/s stability for instrument
- Data rate to ground: ~ 2 Gbit/day, DSN, X-band
- Total Cost: $372 M

- JPL roles: PI, project management, system engineering, optics subsystem, instrument subsystems
- Other Agencies: LLNL, Troy Barbee, Optics Lead
- Industrial partner roles
  - Xinetics: Mark Ealey, Optics Lead
    - AMT Optics
  - Ball Aerospace or General Dynamics
    - Bus
  - Teledyne: Detectors



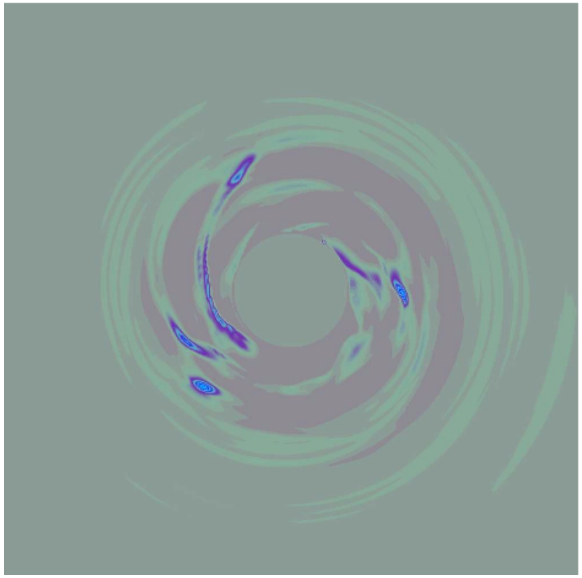
PI and Science Team Backgrounds

- Pravdo (PI) and Shaklan (Co-I) are the PIs of STEPS and have published several refereed papers on astrometry and the discoveries of companions to low-mass stars. Shaklan is the instrument scientist of SIM and the architect of TPF-C. Redding (Co-I) is Project Scientist and wavefront sensing and control system lead for AMT, as well as Co-I for its active mirror technology. Serabyn is the PI of the ground-based fiber-nuller coronagraph on Palomar and Keck.
- The Science Team contains a broad range of experts in the field: theory (A. Boss - leader, A. Burrows), ground observations (T. Henry, J. D. Kirkpatrick, I. N. Reid, S. Pravdo), space astrometry (G. F. Benedict, B. McArthur), and instruments (D. Redding, G. Serabyn, S. Shaklan).

Planetary Formation Models

Competing models of Planetary Formation

- Disk Instability Model
  - Jupiter-mass clumps form quickly around a 0.5 M_{sun} star by disk instability (Boss, 2006)
  - Predicts that giant planets should be common around M dwarf stars on orbits inside ~2 AU
    - Only 3 M-dwarf stars with planets found so far by RV and ~4 by microlensing – largely unexplored territory



Growth of Planetary Cores and Envelopes

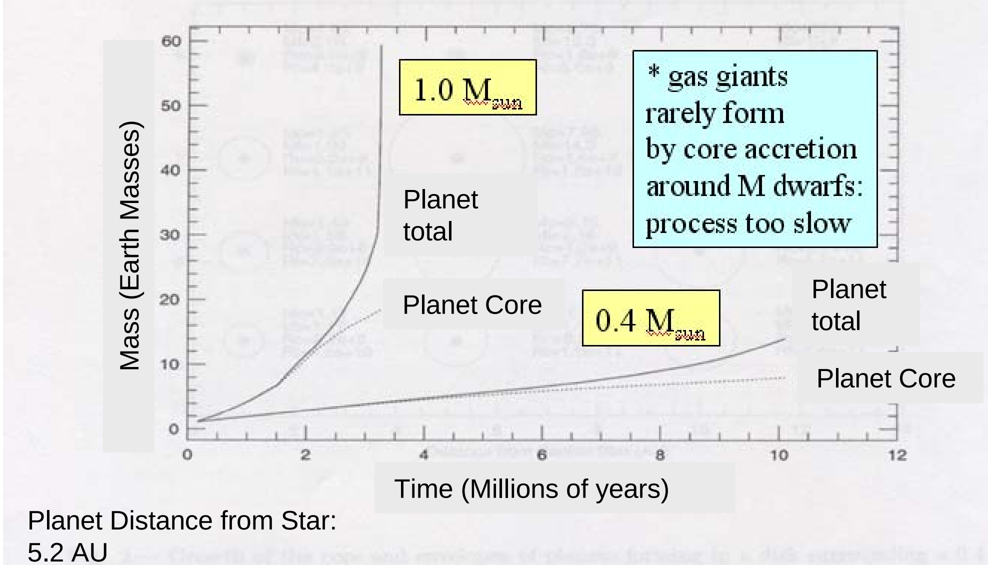


Fig. 1.— Growth of the core and envelopes of planets at 5.2 AU in disks orbiting stars of two different masses. The upper curves show the time-dependent core mass (dotted curve) and total mass (solid curve) for a planet forming in a disk surrounding a $1M_{\odot}$ star. The lower curves show the time dependence of the core mass (dotted curve) and total mass (solid curve) for a planet forming in a disk around a $0.4M_{\odot}$ star. After 10 Myr, the disk masses become extremely low, which effectively halts further planetary growth. The planet orbiting the M star gains its mass more slowly and stops its growth at a relatively low mass $M \approx 14M_{\oplus}$.

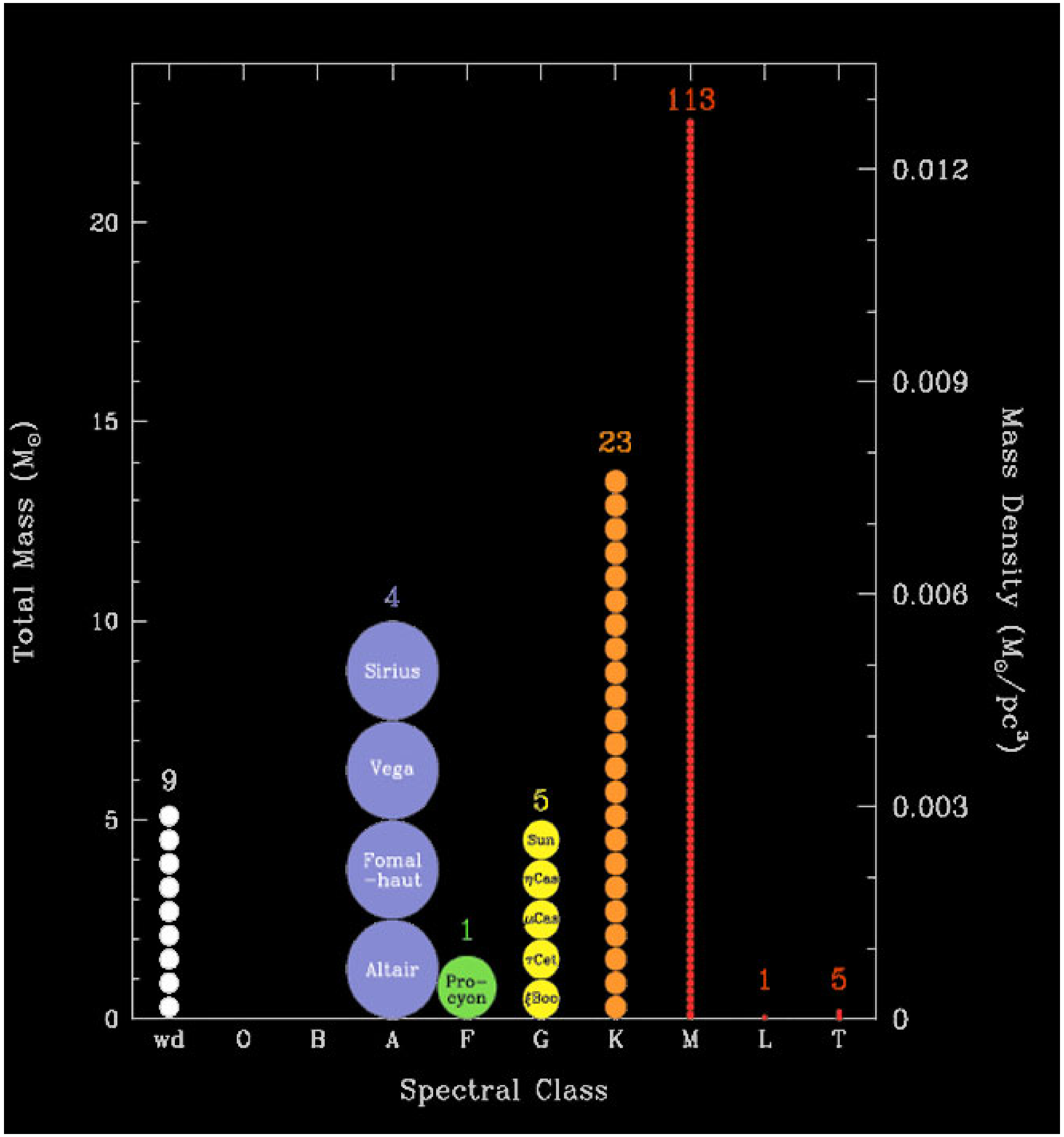
- Core Accretion Model
  - Gas giant planets around solar-mass stars may form within a few million years, the typical lifetime of the gaseous disk
  - Gas giant planets form much slower around M dwarf stars and so may end up as failed cores rather than as gas giant planets (Laughlin et al 2004)

Science Objectives

- GIMLI observations would help to resolve the debate between the competing theories of planetary formation – core accretion and disk instability – that predict few or many companions to M-dwarfs inside a few AU, respectively
  - Determine the frequency of Extrasolar Giant Planet (EGP) and Brown Dwarf (BD) companions to the most common stars – main sequence M dwarf stars – and to BDs
  - Determine the masses and luminosities of the stars and their companions
    - GIMLI will calibrate the mass-luminosity relation for low-mass stars and BDs by determining their dynamical masses, thereby constraining theoretical models of the great majority of stars
    - The existing knowledge of masses of low-mass stars, BDs, and EGPs, is rudimentary. (10 M-dwarfs in Mass-Luminosity Relation, ~5 BDs with dynamically-determined masses, 200 planets with mass ambiguity-only 3 low-mass systems with planets)
- GIMLI addresses NASA's strategic goal to perform an inventory of planets and to address their formation and evolution.

Scientific Merit and Impact

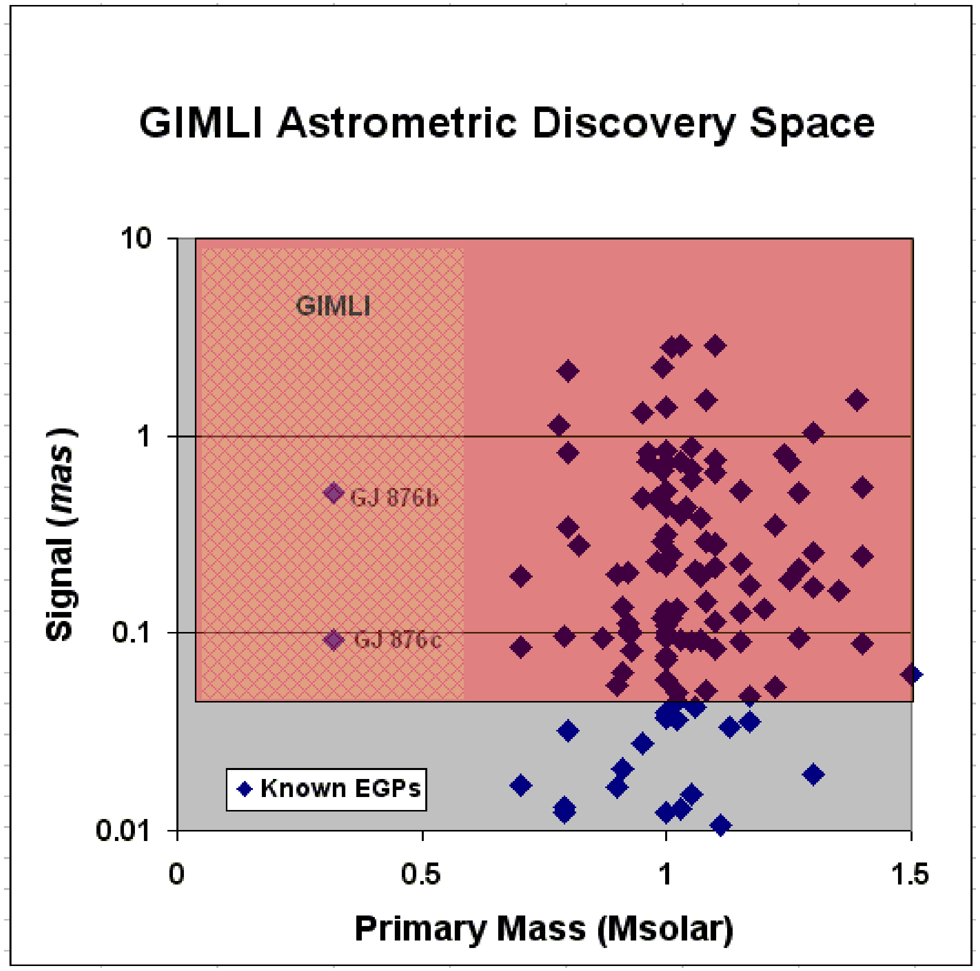
- M dwarf stars dominate the population of the Galaxy
  - M dwarf stars are low-mass, main sequence, red stars
  - Constitute > 70% of all stars
  - Provide a wide range of luminosities
    - Leads to variety of planetary environments
  - There are approximately 2000 M dwarfs within 20 parsecs



Stars of different spectral classes within 8 parsecs, North of Dec. = -30°. The numbers above each class represent the number of stars within that class.

Scientific Merit and Impact

- GIMLI will constrain theories of planetary formation and evolution by:
  - Targeting nearby young stars
  - Searching a volume-limited sample for companions down to Uranus mass in orbits from 0.3-5 yr
  - Testing the metallicity effect
  - Calibrating the mass-luminosity relation for low-mass stars and brown dwarfs by determining their dynamical masses
- GIMLI will find giant planets that could have habitable moons as well as inner terrestrial worlds.

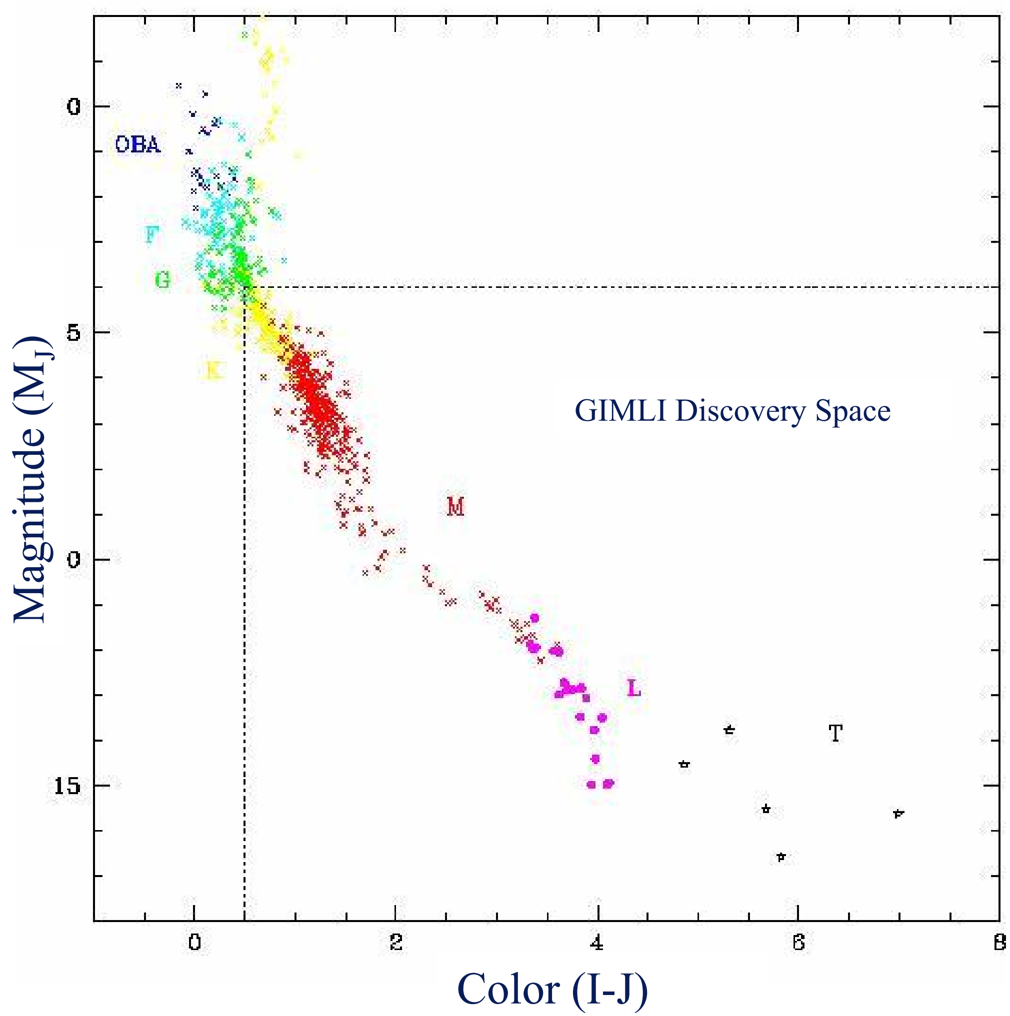


GIMLI explores new regions and measures the inclination angles of known planetary systems.

Science Techniques

- GIMLI will be a 1.4-m aperture space telescope that detects extrasolar planets by two complementary techniques
  - Primary technique is indirect detection by astrometry with a precision of 50 μas
  - Secondary technique is direct detection by coronagraphic imaging with an inner working angle of ~0.5 lambda/D (~100 mas)
- These two techniques are complementary: astrometry finds inner planets, coronagraphy finds outer planets

The Near-Infrared HR Diagram



GIMLI M Dwarf Targets

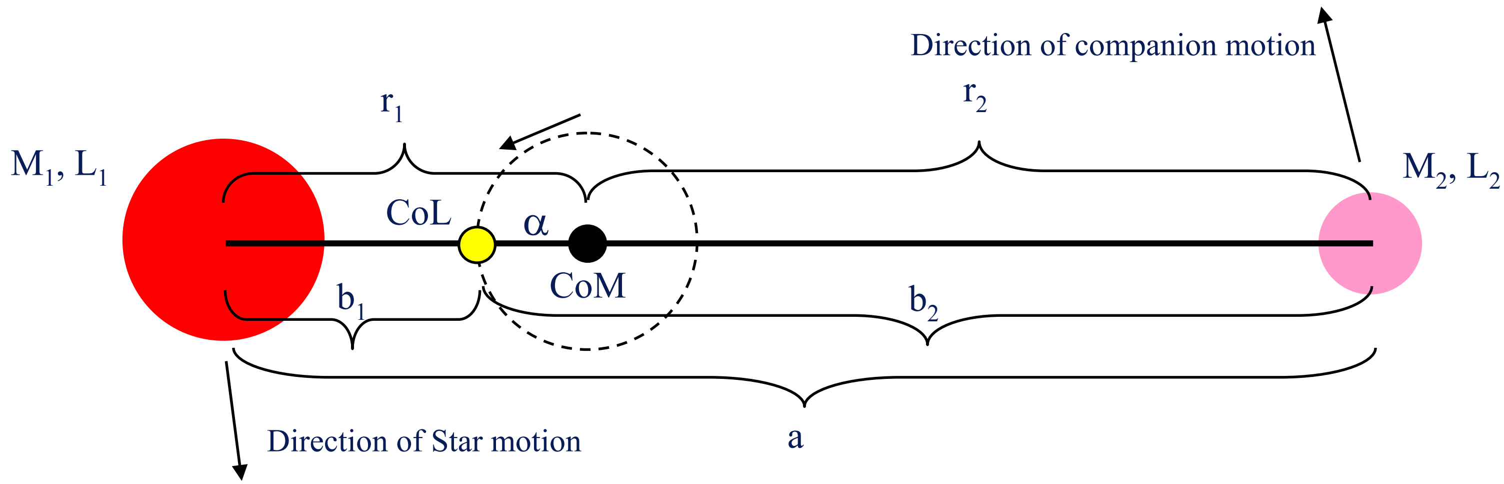
Young Star Targets

NAME	Age (My)	D (pc)	Mass (M_Jup)*	Sep. (AU)*
Lupus	1	150	0.90	13.8
Taurus	1	140	0.84	12.9
Orion Nebula Cluster	1-2	460	2.77	42.4
Rho Ophiuchi	2	125	0.75	11.5
MBM 12	2	350	2.11	32.2
IC 348	2	320	1.93	29.5
Sigma Orionis	3	350	2.11	32.2
Upper Scorpius	5	145	0.87	13.4
TW Hydrae Assoc	8	20-130	0.12	1.8
Beta Pictoris	12	20-50	0.12	1.8
Tucana-Horologium	20	30-70	0.18	2.8
AB Doradus	50	15-50	0.09	1.4
Alpha Persei	90	180	1.08	16.6
Pleiades	100	135	0.81	12.4

*50 µas precision, 0.2 Msolar, 5 year mission, 1.4-m aperture

Astrometric Measurements

GIMLI observes the motion of the Center of Light (CoL) about the Center of Mass (CoM). This is called the *photocentric motion*.



$f = M_2 / M_{tot}$ (fractional mass)
$\beta = L_2 / L_{tot}$ (fractional light)

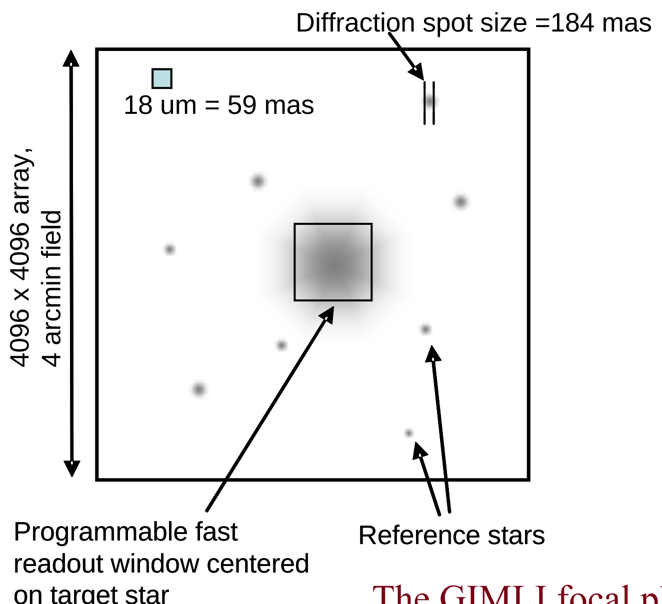
CoM and CoL:
r1 = a*M2/MT = a*f
b1 = a*L2/LT= a*β

$$\boxed{\alpha = \text{CoL} - \text{CoM} = r_1 - b_1 = a^*(f-\beta)}$$

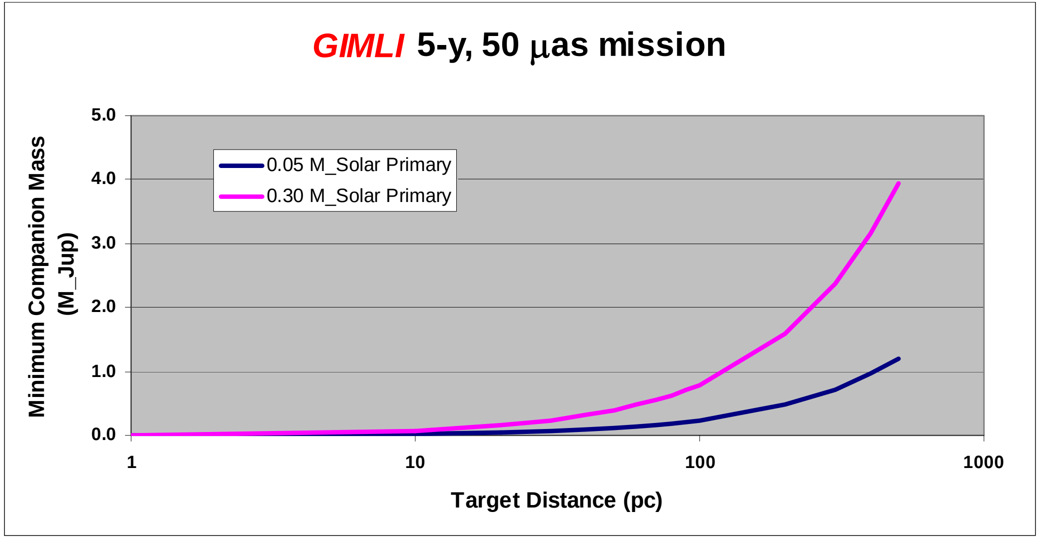
α/a = ratio of photocentric to Keplerian orbit= f - β

Astrometric Performance

- Astrometric Observing Parameters
  - Aperture: 1.4-m
  - Diffraction spot size: 225 milliarcsec (mas)
  - Total number of pixels: 4096 x 4096
  - Plate scale: 59 mas/pixel
  - Field of view: 4 arcmin square
  - Astrometric precision: 50 µas
  - Pixel precision: 1/1000



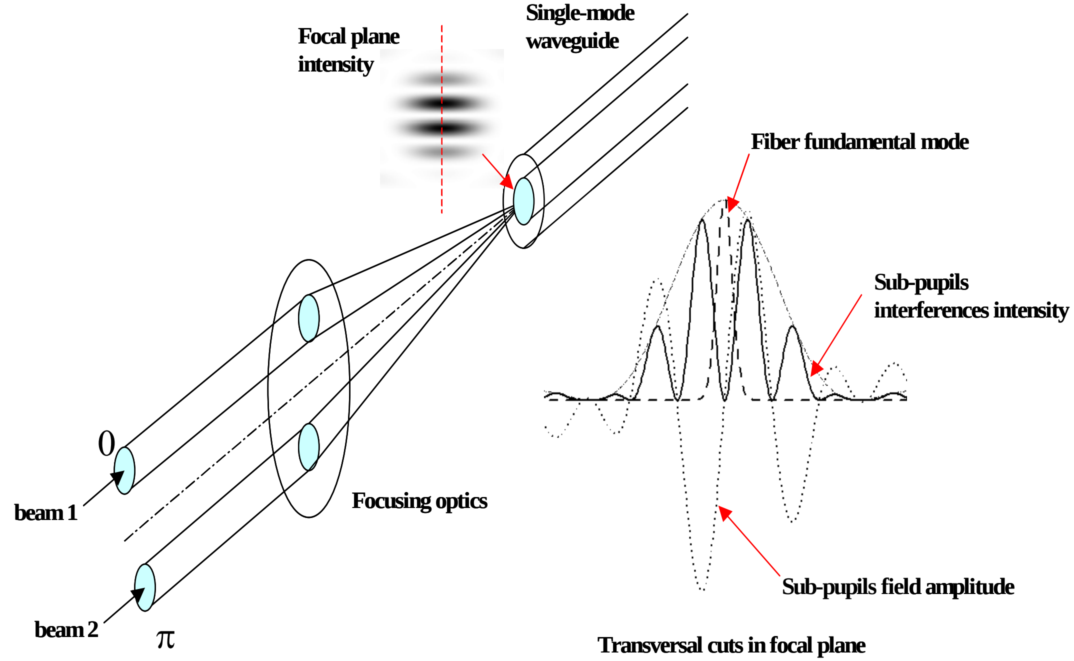
The GIMLI focal plane



Minimum companion mass as a function of distance to the target star for a Brown Dwarf (0.05 M_{solar}) and an M-dwarf (0.3 M_{solar}) target star. These masses are based on 50 µas precision for a 5 year mission.

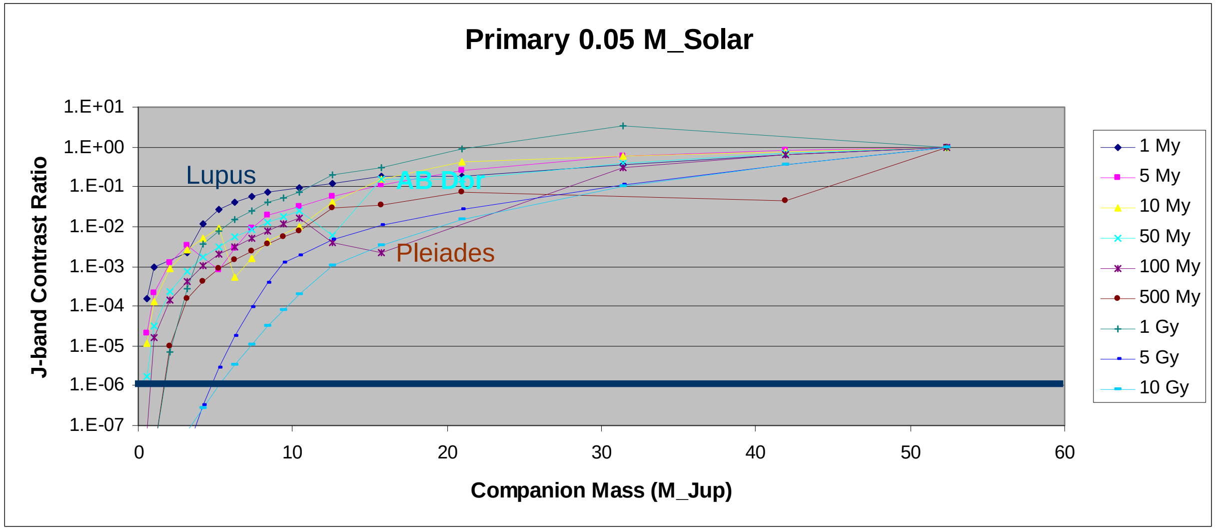
Coronagraph

- Coronagraph Observing Parameters
  - Aperture: 1.4 m
  - Inner Working Angle: 92 milliarcsec (mas)
  - Outer Working Angle: 184 mas
  - Contrast: 1e-6
  - Spectral Resolution: ~ 100
  - Detector: Uses small region of astrometric detector
  - Pointing Requirement: 0.1 mas integrated for f > 1Hz (J = 10)
  - Observing Mode: set every 30 deg about Line of Sight



The Fiber Nuller: the fiber itself is the beam-combiner

Contrast Ratios for a Brown Dwarf Star



J-Band Contrast Ratios as a function of planet mass and age for a Brown Dwarf (0.05 M_{solar}) target star. GIMLI can detect young planets down to Jupiter mass

Contrast Ratios for an M-Dwarf Star

J-Band Contrast Ratios as a function of planet mass and age for a mid-mass M-dwarf target star (0.3 M_{solar}). GIMLI can detect younger planets and older Brown Dwarf companions to M-dwarfs.